63-2-5

October 1962

Report No. 0705-82Q-1

FIRST QUARTERLY PROGRESS REPORT

EVALUATION OF HIGH-NICKEL STEEL FOR APPLICATION IN LARGE BOOSTER MOTOR FABRICATION

Contract No. AF 33(657)-8740

Task No. 738101

Period Covered:
July Through September

31

W. O. 0705

AEROJET-GENERAL CORPORATION
SOLID ROCKET PLANT • SACRAMENTO, CALIFORNIA
A SUBSIDIARY OF THE GENERAL TIRE & RUBBER COMPANY

Report No. 0705-82Q-1

EVALUATION OF HIGH-NICKEL STEEL FOR APPLICATION IN LARGE BOOSTER MOTOR FABRICATION

First Quarterly Progress Report to
Aeronautical Systems Division
United States Air Force
Wright Patterson Air Force Base, Ohio

Contract No. AF 33(657)-8740

Task No. 738101

Period Covered:
July Through September

Approved by:

Robert E. Anderson

Robert E. Anderson
Supervisor
Joining and Structural
Metallurgy Section

Approved by:

Walter S. Tenner

Walter S. Tenner,
Department Manager
Chamber Components and
Fabrication Support
Solid Rocket Plant

AEROJET GENERAL TIRE GENERAL SOLID ROCKET PLANT SACRAMENTO, CALIFORNIA

A SUBSIDIARY OF THE GENERAL TIRE & RUBBER COMPANY

PREFACE

The program reported herein was sponsored by the Aeronautical Systems Division, Wright Patterson Air Force Base, under Contract No. AF 33(657) 8740, Task No. 738101. The work was performed under the direction of R. E. Anderson assisted by the following research personnel: P. P. Crimmins, H. R. Smith and E. L. Hoffman.

ABSTRACT

This report outlines the results of investigations conducted during the period of 1 July through 30 September 1962 to determine the mechanical and metallurgical properties and weldability of the 18% nickel alloy steels. This work is being performed under Air Force Contract No. AF 33(657)-8740, Task No. 738101.

The information in this first quarterly report relates specifically to the results of mill processing evaluations and the initial studies to establish the mechanical and metallurgical properties of parent-metal 18% nickel alloy steels. In addition, the results of preliminary studies to determine the effects of different weld-wire compositions on weldability and resultant weld properties are presented.

I. INTRODUCTION

Since the first experimental information on the high-nickel, maraging, alloy steels was released by the International Nickel Corp. about 2 years ago, it has become increasingly evident that this class of material has properties which are uniquely advantageous to solid-propellant rocket chambers, especially those of a very large diameter. Specifically, these properties are (1) usable yield strengths in the range of 250,000 to 300,000 psi; (2) exceptional toughness and crack resistance at these high strength levels; (3) simplified thermal processing wherein a moderate-temperature aging cycle has replaced the austenitizing heat treatment characteristic of the low-alloy steels, which required large complex drop-bottom furnaces; (4) the material demonstrates good ductility. In recognition of these advantages, a continuous material evaluation and test program has been initiated at Aerojet-General under Air Force Contract AF 33(657)-8740, Task Number 738101 to investigate the 18% nickel alloy steels. The overall objective of this program is to provide technical information regarding this material and the effect of mill process variables, alloying variables, heat-treatment processing variables, and welding variables so as to lead directly to the preparation of materials and processing specifications applicable to the fabrication of large-diameter (more than 200 in.) rocket-motor case segments by rolling and welding.

II. OBJECTIVES

This program is divided into four phases. The objective of each is as follows:

PHASE I: Establish the effect of mill practice on material quality and properties.

PHASE II: Develop adequate data to establish maximum usable strength levels by correlating tensile strength with fracture toughness and notch sensitivity.

II, Objectives (cont.)

PHASE III: Develop reliable welding techniques that will result in mechanical properties equivalent to those of parent material.

PHASE IV: Prepare material and process specifications by use of the information generated in the subject program.

III. TECHNICAL PROGRESS SUMMARY

In accordance with the program outline supplied as the first monthly progress report, dated 13 August 1962, the following technical progress has been achieved.

A. PHASE I: ESTABLISHMENT OF MILL PRACTICES

Nine steel mills and the International Nickel Co. have been visited to discuss melting and mill processing practices and their effect on the properties of the 18% nickel maraging steel. Companies and personnel contacted are listed in Table 1.

1. Production History

Production capacity is adequate to supply the Air Force's foreseeable needs for large rocket chambers, though specific tonnage capacities for each company are difficult to obtain. Such items would depend on demand and how many furnaces would be allocated to the procuring of the maraging steels. The production history of each company to date is as follows:

a. Bethlehem Steel Co.

This company has melted one 7-ton electric-furnace heat and most of the yield was purchased by Aerojet-General. They are in the

III, A, Phase I: Establishment of Mill Practices (cont.)

process of pouring another heat of the same size and composition. Their personnel would not estimate a production capacity, since this depends on how many furnaces they would want to use in producing the material. This, in turn, depends on demand. They are confident that their overall capacity is sufficient to supply the demands of the missile industry. However, for the present, they have allocated only the one 7-ton electric furnace to producing maraging steel. Plate can be rolled on mills ranging in width to 120 in. Bethlehem's current price is $2.25/lb for plate material; however, they suggested that this may decrease if production increases.

b. Carpenter Steel Co.

Carpenter has produced one 1-ton air-induction heat, one 2 1/2-ton air-induction heat, and four 12 1/2-ton electric-furnace heats of materials. All of these were consutrode remelted. Carpenter personnel say that production depends on demand. For the present, they have adequate electric and air-induction furnace capacity to feed two 20 and one 28 in. consutrode remelting furnaces. Carpenter does not have production plate-rolling facilities and would prefer to supply bar and rod or small specialty items such as weld wire. Present price information is based on vacuum-arc-remelted bars, which are $2.50/lb.

c. Allegheny Ludlum Corp.

Allegheny Ludlum has poured 50 induction-melted 5000-lb., 6 electric-furnace 10-ton, and one electric-furnace 12-ton heats of 18%-nickel material. All of these were vacuum-arc remelted to various-size ingots. Their production capacity is 300,000 tons/year air-melted and 1,500 tons/year vacuum-arc-remelted material. Vacuum-arc-remelted ingots can be poured in diameters of 50 in. If orders for vacuum-degassed material are

III, A, Phase I: Establishment of Mill Practices (cont.)

received, their Dunkirk facility has a 15-ton ladle degassing unit and a 25-ton stream degassing unit. Allegheny has contracted with Lukens Steel Co. to roll wide (205 in.) plate and report that delivery and product quality have been quite satisfactory. Prices are tailored to the producing unit, where the unit used is dictated by the melting technique specified and the size of the order. A price of \$3.46/lb for vacuum-arc-remelted 250-ksi plate has been quoted to Aerojet General.

d. Special Metals Corp.

This company has produced a large number of small vacuum-induction and consutrode-remelted heats. Their activities are concentrated in vacuum melting and remelting. They have no air-melt facilities, and no rolling facilities. Their product is considered to be of very high quality because they charge electrolytically pure materials, and, as a result, it is quite expensive. Consequently, they have aimed their maraging products toward weld wires and other specialty items.

e. United States Steel Corp.

U. S. Steel has produced a 20-ton air-melted heat, which yielded about 11 tons of material. Four slabs were prepared, two going to 3/4 in. plate, 1 to 1/2-in. plate, and 1 to 1/4-in. plate, a part of which was sandwich-rolled to sheet. Another 20-ton air-melted heat is being poured, and this is destined to be processed into 6, 8, and 10-in. round-corner square billets as well as some plate. U. S. Steel, as the others, say production capacity is based on demand, and, if warranted, 4000 tons per month could be

III, A, Phase I: Establishment of Mill Practices (cont.)

produced. This corporation and Bethlehem are the only two that have integrated facilities beginning with melting and ending with a possible 160-in.-wide plate. U. S. Steel is currently "shaking down" their vacuum degassing facility, and this together with a rolling mill capable of rolling plate more than 200 in. wide will be available early next year. U. S. Steel has quoted a price of $1.40/lb for plate based on melting costs and considering a projected heat loss estimated from previous experience with other steels.

f. Republic Steel Co.

This company is aggressively attempting to supply the needs of the missiles industry. 18% Ni maraging steels have been produced for evaluations aimed at supplying optimum materials for landing gears, submarine hulls, and large rocket-motor chambers. In all cases, material was consutrode-remelted. Production capacities and prices were not specifically quoted because of the complexity of demand and capacity.

g. Latrobe Steel Co.

This company has poured six vacuum consumable-electrode production heats. Of these, five were 5000 lb and one was 30,000 lb. Latrobe has one of the country's largest vacuum consumable-electrode melting facilities consisting of one 36, one 30 and two 20-in.-dia vacuum consumable-electrode melting furnaces. They rate their total production capacity at 535,000 lb of vacuum-remelted material per week. Products made have been billets, bars, plate, and thin plate. If an order is received for plate more than about 1 foot wide, Latrobe has negotiated an agreement with Lukens to have their material rolled. Officials at the company are reticent to state opinions concerning projected prices; however, an estimate of around $2.00/lb was stated for air-melted plate and $2.50/lb for consumable vacuum-melted plate.

III, A, Phase I: Establishment of Mill Practices (cont.)

h. Vanadium Alloys Steel Corp.

This company has poured more production heats of 18% Ni material than any other. Approximately 125 vacuum-arc-remelted heats ranging from 1000 lb to one at 30,000 lb have been poured. VASCO's production capacity is now 3.5 to 4 million lb per year with a 9- to 10-million-lb/year capacity projected to November 1962. Their consumable-electrode-melted ingots are 24 in. in diameter and weigh 9,000 lb, and, by the end of the year, they expect to produce material 33 in. in diameter and weighing about 15,000 lb. Personnel at VASCO have stated that they do not expect to roll wide plate through Lukens or other companies with large rolling mills but, instead, will concentrate on the smaller specialty items, such as sheet and bar. In this regard, they have a wide variation of furnace capacities, allowing them to supply quantities from less than 100 lb to 15 tons. One of their specialties is vacuum arc-remelted weld wires.

2. <u>Melting and Conversion Practice</u>

a. Basic Electric Furnace Practice

No initial heats were melted by vacuum induction techniques at Allegheny-Ludlum, Vanadium Alloys, and others. However, production-sized heats are now generally made in basic electric furnaces. The International Nickel Co. has established a basic electric furnace procedure and has offered consultation services to any company intending to produce the maraging steels. Although each producer may vary somewhat from Inco's recommended practice depending on his plant layout and experience, maraging steels are generally melted in three basic stages as follows:

III, A, Phase I: Establishment of Mill Practices (cont.)

(1) A high-quality charge is fed into the furnace. This charge contains scrap iron having 0.20 to 0.40%, carbon with low sulphur, phosphorous, and other impurities; molybdenum as ferromolybdenum; electrolytic nickel and cobalt; and slag ingredients totalling approximately 2% by volume of the melt. The slag ingredients are CaO and SiO_2 in amounts that produce a basicity ratio of approximately 2:1, based on scrap quality. Variations of slag ingredients involving the use of CaO alone or CaO plus fluorspar (CaF_2) have been used with good results. When the heat becomes molten, it is blown with O_2. The carbon reacts with the oxygen, causing considerable boiling and turbulence, which provides the mixing action required to maximize removal of P, Mn, Si, H_2, and N_2. CaO then acts as a catalyst to stabalize P_2O_5.

(2) The oxidizing slag is raked out of the furnace and the refining slag is added (1-1/2 to 2% by volume). This slag is composed of six parts CaO, three parts fluorspar, and one part granular aluminum. After O_2 and S have been removed, adjustments are made to balance the composition.

(3) The refining slag is removed, leaving only enough to protect the melt. CaO and Al in the proportion of 3 CaO to 1 Al are added to bring the slag volume to approximately 2%. The Al is pushed down into the melt and acts as a final deoxidizer and possibly as a grain refiner. The required amount of titanium metal is then added in the same manner. Previous work at Inco indicates that Zr and B contribute to stress-corrosion resistance and, for this reason, are added to maraging steel as Ni Zr and ferroboron, respectively. The last, and possibly the most important addition, is Ca metal. A maximum of 0.06 wt% Ca is added in 0.02% increments to combine with any residual S ($>$.005%) as CaS_2). The sulphides thus formed are globular and not concentrated in the grain boundaries. This calcium addition is made to prevent the formation of titanium sulphide stringers at the grain boundaries, which would cause embrittlement. Finally, the melt is teemed into an ingot.

III, A, Phase I; Establishment of Mill Practices (cont.)

It is generally considered desirable to degas at this time if the heat is not to be vacuum arc-remelted. Degassing is conducted either by having both the crucible and ingot mold under vacuum during teeming (stream degassing) or by having only the mold enclosed in a vacuum (ladle degassing). Of the companies interviewed, only Bethlehem and Allegheny Ludlum are producing air-melted and vacuum-degassed material.

b. Consumable-Electrode Vacuum Remelting

This process is used by all companies visited except Bethlehem and United States Steel. The advantage cited for the process lies with a superior structure from the standpoint of segregation and cleanliness.

The primary-arc or induction-melted material is poured into an elongated cylindrical mold to produce an electrode for vacuum arc remelting.

The electrode is top- and bottom-trimmed and the total surface is ground, wire-brushed, and wiped with acetone. These precautions are necessary to produce the necessary cleanliness in the subsequent remelted ingot. The electrode is then placed in the water-cooled, copper crucible of a consumable electrode vacuum furnace. A vacuum of 1 to 5 microns Hg is introduced to the system and the power input and electrode travel rate are carefully controlled to produce the required pool configuration. Improper control results in O_2 entrapment and a phenomenon referred to as "freckling". "Freckles" appear to be high-alloy areas and areas containing low-melting carbides.

III, A, Phase I: Establishment of Mill Practices (cont.)

c. Vacuum Induction Melting

For small quantities (5000 lb or less) vacuum induction melting is sometimes used. In this system, an ultrapure charge is put in the melting crucible. A current is induced in the charge, thus generating the heat necessary for melting. The crucible and ingot mold are both contained in a vacuum, in which the heat is poured. Since there can be no slagging action in this process, the only refinement taking place is removal of gaseous interstitials. Carpenter Steel and Special Metals used this process for preparing ingots to be used in the manufacture of weld wire.

d. Breakdown Practice

Normal precautions are taken to avoid hydrogen flaking during primary conversion. The ingot is stripped as hot as possible. The ingot is heated twice at 2300°F during primary breakdown to promote homogenization. The major reduction is effected at 1900°F with finishing temperatures between 1400 and 1500°F. International Nickel Co. recommends a slow (furnace) cool period from rolling temperatures through the M_s to room temperature to avoid any possible hydrogen flaking damage.

The following is a Latrobe Steel rolling schedule, which is representative of the processing procedure for producing plate.

(1) Material was charged to the furnace at 1880°F and the control temperature was raised to 1930°F.

(2) After 45 min, the system reached 1930°F; then the 16- by 16- by 1-3/4-in. bar was reduced seven times at 20% reduction per pass.

III, A, Phase I: Establishment of Mill Practices (cont.)

(3) The material was reheated to 1930°F and the thickness was reduced to 0.245 in. in three 20%-reduction passes. From there, the material was sent to the finishing mill and reduced to 0.150 in. beginning at 1900°F and finishing below 1700°F.

(4) Immediately after the first piece was processed prior to reheating (approximately 5 min lapsed time) the 24-in.-square slab was rolled beginning at 1930°F.

(5) With 12 20%-reduction passes, this material was reduced to 0.380 in. The piece was then reheated at 1800°F for 20 min.

(6) The piece was then rolled to the finish size, 0.265 in. thick, in four passes (approximately 8% reduction per pass). The finishing temperature was described as being well below 1700°F.

e. Miscellaneous Items

Some problems have been encountered by certain mills in their initial attempts to produce maraging steels. On the basis of their past experience with high-temperature alloys (A-286, etc.), Carpenter Steel Co. poured a heat that exhibited gross segregates in 12-in.- and 9-in.-long bars cogged from 20-in.-long vacuum arc-remelted ingots. They did not offer information as to the nature of the segregates or what measures they took to remedy the problem. However, succeeding heats have apparently been clean. Personnel at the International Nickel Co. have examined samples of Carpenter material that was described by the producer as being defective and have noted a segregate they have identified as titanium sulphide. As a result of

III, A, Phase I: Establishment of Mill Practices (cont.)

These observations, the importance of imposing requirements for ASTM E45 J&K chart indications of inclusion content in a material specification has been emphasized. Unfortunately, a similar specification does not exist for controlling carbides and nitrides, and this problem remains to be resolved.

The United States Steel Co. has adopted the Inco-recommended melting procedure, but, since they do not vacuum-degas, they repeat their oxidizing and refining slag operations. This, they maintain, is sufficient to reduce the H_2 content to a level where it does not cause flaking during primary conversion.

During the visit to the mills, specific requests were made for thick-section fracture-toughness data. No one offered this type of data, but it is apparently available at Republic. This company has participated with Convair in a contract funded by Wright Field to evaluate materials for B-58 landing-gear application. Materials tested were 18% Ni maraging steels, AISI 4340 air- and consutrode-remelted steel, and Republic's 9% Ni, 4% Co Steel with low and high C levels. The results of this investigation are reported to show that the maraging steels become susceptible to low-stress, plane-strain failures at all strength levels (200 to 300 ksi) in sections more than about 0.200 in. thick. This is reported to have been substantiated by NRL and Bureau of Ships laboratories. However, it is well-known that the drop-weight and explosive-tear tests used to screen materials for submarine hull construction are very stringent. Nevertheless, the question of inadequate plane-strain fracture toughness has been raised, and the importance of the crack-propagation studies being conducted in Phase II is emphasized.

III, Technical Progress Summary (cont.)

B. PHASE II: MATERIAL EVALUATION

1. Task A: Standard Material

a. Aging Response with Longitudinal Tests

The 18%-nickel alloy that has been selected to provide a base-line evaluation is Bethlehem Steel Co., Heat No. 12OD163. This material was air-melted and vacuum-degassed and rolled into 1/2-in.-thick plate. The chemical composition of this heat is shown in Table 2. An inital aging-response evaluation has been completed with 1/4-in.-dia smooth and notch tensile specimens. Aging temperatures of 850, 900, and 950°F for times up to 24 hr have been evaluated by mechanical-property tests (Tables 3, 4, and 5 and Figures 1 through 4). Figure 1 contains the average curves for all temperatures as a function of time, while Figures 2, 3, and 4 are the plots of individual temperatures and contain all data points developed to date. The average curves are typical of those predicted in the program outline. As indicated in Figure 2, the 850°F, 4-hr treatment results in an underaged condition; the yield strength developed by this treatment is about 235 ksi. Aging apparently proceeds for all times up to 24 hr because, at this time, the maximum yield strength of about 265 ksi was reached. In view of the chemical composition of this heat, a 265-ksi yield strength should be approximately the maximum abtainable by aging at this temperature. At 900°F, the material appears to be underaged (yield strength at 1 hr, 220 ksi) until an exposure time of 2 to 3 hr, when maximum tensile-strength values for the 900°F aging temperature were abtained. These tensile properties corresponded to a yield strength of approximately 250 ksi. At 950°F (Figure 4), full strength is abtained very quickly (1/2 to 1 hr), and further aging reduces the yield strength to about 230 ksi.

III, B, Phase II: Material Evaluation (cont.)

As indicated in Table 3, considerable scatter exists between individual data points for each aging cycle evaluated. During the aging of these initial test specimens, an argon flood was used to reduce surface oxidation. However, insufficient heating of the argon was found to cause considerable temperature variation within the furnace, resulting in the differences in tensile properties shown in Table 3. In view of the wide scatter in properties, additional specimens were processed without an argon atmosphere. The results of this second group of test specimens are shown in Table 4. As indicated, good uniformity is shown in properties of individual specimens processed according to the same aging cycle. Also, oxidation of the specimens during aging was negligible. In view of these results, additional specimens were then processed to more accurately establish the complete aging-response curves. The results of this third processing sequence are shown in Table 5. In addition to the test specimens required to fully characterize the aging response; the 900°F 4-hr; 950°F, 4-hr; and 950°F 8-hr aging cycles were repeated to check reproducibility between cycles. As indicated in Table 5, the uniformity of tensile properties of individual specimens processed according to the same cycle was good. However, uniformity of results between groups of data representing common aging cycles in Tables 4 and 5 was not good. For example, 0.2% offset yield strengths of specimens aged during the second run (Table 4) at 900°F for 4 hr averaged 241 ksi while those processed according to the same aging cycle during the third run (Table 5) averaged 248 ksi. The same magnitude of variation was also indicated for test specimens aged at 950°F for 4 hr and at 950°F for 8 hr. In view of this difference, accurate temperature control (less than ± 10°F) during aging apparently a requirement for predictable aging response in laboratory tests. The furnace in which these specimens were processed had a temperature accuracy of ± 10°F. Additional specimens are now being processed in another furance with special emphasis on temperature control (± 5°F). These additional evaluations are expected to provide curves similar to those already developed but with a reduced scatter of properties.

III, B, Phase II: Material Evaluation (cont.)

Notch specimens with a notch severity (K_t) of 10 were tested in accordance with the program outline. The results of these tests are presented in Table 3. The notch tensile strength varied very little as a function of aging treatment and the notch tensile strengths reported are all well above the ultimate tensile strengths. In view of these results, the notch tensile specimen apparently is not suffeciently sensitive to determine the changes in toughness produced by varying the aging treatments. Consequently, more emphasis is now being placed on obtaining slow notch bend-test results in an effort to obtain a more discriminatory toughness evaluation of aging response and materials.

b. Transverse Direction

The effect of rolling direction on the mechanical properties of Bethlehem Heat No. 120D163 was determined with transverse smooth and notched tensile specimens. These specimens were aged at temperatures of 850°F, 900°F and 950°F for times selected based on the results of longitudinal property tests. The results of the transverse-property tests are presented in Table 6. The transverse tensile properties for the 850°F, 4 hr and the 900°F, 4 hr aging cycles are comparable to those for longitudinal specimens (Tables 4 and 5). However, transverse tensile properties for the 850°F, 8-hr, 950°F, 2-hr, and 950°F, 4 hr aging cycles are higher than those for longitudinal test specimens. In view of the potential inaccuracies in temperature control during aging, it is difficult to draw an accurate conclusion in regard to anisotropy at this time. However, the data shown in Table 6 indicate that the difference in properties due to specimen orientation will not be significant. Tensile specimens are currently being machined to completely rerun this program phase. It is also significant to note that the notch tensile strengths listed in Table 6 are also considerably above the ultimate tensile strength for all aging cycles evaluated.

III, B, Phase II: Material Evaluation (cont.)

c. Solution Treating

The program outline encompasses an evaluation to determine the effect of solution annealing on properties after aging. Specimens are being prepared for heat treatment and testing.

2. Task B: Additional Materials

a. Materials on Hand

The effect of melting technique on 250 - ksi material has been partially determined. Air-melted material was supplied by the United States Steel Corp. and vacuum arc-remelted material by the Republic Steel Corp. The chemical analyses of these heats are shown in Table 2, while Tables 7 and 8, respectively, list the mechanical properties of the U. S. Steel and Republic Steel materials.

As indicated in Table 7, the results obtained in testing the air-melted U. S. Steel material are comparable to those shown in Tables 4 through 6 for the Bethlehem alloy. There is some scatter in results: however, the tensile properties appear to follow the same general trends previously established for the Bethlehem material. The notch tensile strength exceeds the ultimate tensile strength after aging at 900°F for 4 hr; however, the data for the 950°F 2- 4-hr treatment indicate one value for each cycle that does not exceed the ultimate tensile strength. Also, the average transverse tensile properties, after aging at 900°F for 4 hr are comparable to those in the longitudinal direction. After aging at 950°F for 2 hr there is considerable difference in tensile strength between the longitudinal and transverse directions.

III, B, Phase II: Material Evaluation (cont.)

The tensile strengths shown in Table 8 for the Republic alloy (Heat No. 3888471) are very low. On the basis of the chemical analysis of the Republic material shown in Table 2, the tensile strength of this alloy was expected to approximate or exceed those for the Bethlehem and the U. S. Steel alloys. The reason for the apparent anomaly in results cannot be explained at this time. Extensive chemical and metallurgical investigations are under way in an effort to further evaluate this material. Additional tensile specimens are also being processed for testing.

b. Materials to Be Procured

In accordance with the program outline, additional materials have been ordered for evaluation. The status of purchase orders for these alloys is as follows:

Material	Vendor	Promised Delivery
200-ksi air-melted	Allegheny-Ludlum Corp.	
(a) 1/2 in. plate		25 October 1962
(b) 4 in. bar		10 December 1962
200-ksi vacuum-degassed	Lukens Steel Co.	
(a) 1/2 in. plate		Received
300-ksi vacuum-arc-remelted	Vanadium Alloys Steel Co.	
(a) 1/2 in. plate		25 October 1962
(b) 4 in. bar		25 October 1962

3. Task C: Crack Propagation

Slow notch bend-test specimens of the standard Bethlehem material have been machined and heat-treated. Testing is currently being conducted.

III, Technical Progress Summary (cont.)

C. PHASE III: WELDING STUDIES

1. Task A: Effect of Weld Deposit Composition

a. Weld Wires on Hand

Six weld wires, with various amounts of titanium and cobalt have been used for TIG (tungsten inert gas) welding of the standard Bethlehem air-melted vacuum-degassed material. Typical welding parameters used in processing these test plates are shown in Table 9, the chemical composition (mill-furnished) of these weld wires and the base plate material, Bethlehem Heat No. 120D163, are shown in Table 10. The two additional base plate materials previously supplied by Republic Steel Corp. and U.S. Steel Corp., will also be used to further verify these results. The chemical compositions of these two additional materials are shown in Table 2.

The results of transverse weld tests are presented in Table 11. Both notched and unnotched tensile specimens were used in these tests. All specimens were aged at 900°F for 4 hr prior to testing. The data shown in Table 11 show little significant difference between the tensile properties of specimens processed with the different weld wires. This effect is indicated for ultimate strength, yield strength, percent elongation, and reduction in area. There is, however, a pronounced difference in notch tensile strength between welds made with the different weld wires. These data indicate that welds made with the 7C-093 wire result in the highest strength in combination with high notch tensile strength. Table 12 shows X-ray inspection results of the test plates processed. The plates welded with the 7C-093 weld wire also appear superior to plates welded with the other five wires. Consequently, 7C-093 weld wire has been selected as the prime candidate for the next program phases.

III, C, Phase III: Welding Studies (cont.)

In addition to the 7C-093 weld wire, the 7C-090 wire has been selected as a backup material even though the results of the radiographic inspection (Table 12) showed that welds processed with this wire composition were of poor quality primarily due to porosity and inclusions. In spite of the substandard welds, evidence of a high ratio of transverse-weld notched to unnotched tensile strength is indicated by the results shown in Table 11. The prevalence of weld discontinuities is attributed to the high titanium content of the 7C-090 wire. Variations in welding procedure will be investigated to determine if weld quality can be improved with the notch tensile strength maintained or increased. It would be advantageous to further investigate 7C-090 wire for TIG welding because this material is expected to be the prime candidate wire for submerged-arc welding and/or MIG (metallic inert gas) welding because of the expected titanium loss across the arc when these pocesses are used.

The data shown in Table 11, show, that while the titanium and cobalt content of the weld wires varies widely, little difference is noted in yield and ultimate strength of the tensile specimens. Past experience has indicated that little alloy is lost across the arc during welding by the TIG process. Consequently, significant differences in strength were expected between welds processed with the different weld wires. Extensive metallurgical and chemical analyses of welds made with each weld wire are being conducted to explain why differences in strength did not occure. One possible explanation may be that the weld strength, particularly in specimens processed with high-alloy weld wire, exceeded that of the parent material and, consequently, failed outside the weld zone. This explanation is supported in part by the location of failure shown in Table 11. However, lower notch tensile properties would be expected for the higher-strength (1.64% titanium) welds. Since this later effect was not produced, the additional metallurgical and chemical analyses currently under way must be completed before a complete evaluation can be made of the weld mechanical properties shown in Table 11.

III. Technical Progress Summary (cont.)

D. PHASE IV: SPECIFICATIONS

A tentative material specification covering the purchase requirements for plate, sheet, and strip material for the 18%-nickel alloys is shown in Appendix A.

TABLE 1

STEEL COMPANIES VISITED TO ESTABLISH MILL PRACTICES AND PERSONNEL CONTACTED

1. Latrobe Steel Company, Latrobe, Pennsylvania

    Mr. Berger Johnson, Sales
    Dr. Edward Becht, Research

2. Vanadium Alloys Steel Company, Latrobe, Pennsylvania

    Mr. Allen Johnson, Research
    Mr. Dan Yates, Research

3. Allegheny-Ludlum Steel Company, Brackenridge, Pennsylvania, and Watervliet

    Mr. Ray Lula, Research
    Mr. Ralph DeVreis, Special Products Development

4. Bethlehem Steel Company, Bethlehem, Pennsylvania

    Mr. R. Metzger, Missile Products Sales
    Mr. J. Clark, Assistant Mill Metallurgist

5. Carpenter Steel Company, Reading, Pennsylvania

    Mr. J. Lynch, Special Products Sales
    Mr. M. Sullivan, Metallurgist

6. Special Metals Corporation, New Hartford, New York

    Mr. W. Boesch, Manager, Technical Services
    Mr. C. Freer, Customer Services

7. United States Steel Corporation, Pittsburgh, Pennsylvania

    Mr. E. VanMeter, Metallurgical Engineer, Alloy Steels Metallurgy, Steel Operating Division

8. Republic Steel Corporation, Massilon, Ohio

    Mr. R. J. Place, Sales Engineer
    Mr. D. Whitney, Special Products Sales
    Mr. W. Barcle, Supervisor, Research and Development

9. International Nickel Company, New York, New York

    Mr. C. C. Clark, Technical Services, Development and Research Division
    Mr. L. Diran, Metallurgical Services

TABLE 2

CHEMICAL COMPOSITION OF MATERIAL ON HAND
(Mill-Certified Analysis)

Material Source and Heat No.	Composition									
	C	Mn	P	S	Si	Ni	Al	Ti	Mo	Co
Bethlehem plate heat No. 120D163	.017	.06	.005	.004	.18	17.84	.12	.55	4.80	8.25
Republic plate heat No. 3888471	.025	.11	.006	.004	.09	18.74	.08	.75	4.75	8.86
Republic plate heat No. 3888472	.026	.11	.006	.006	.07	18.46	.08	.62	4.80	8.82
Republic plate heat No. 3888473	.026	.08	.006	.007	.05	18.38	.07	.67	4.80	8.68
U. S. Steel	.02	.04	.004	.009	.08	17.83	.11	.46	4.70	7.41

TABLE 3

**LONGITUDINAL TENSILE PROPERTIES OF STANDARD MATERI
TEST SERIES "A", BETHLEHEM 1/2-in. PLATE, HEAT NO. 120D
AS HOT-ROLLED AND AGED**

Heat Treatment	0.2% Offset Yield Strength, Ksi	Ultimate Tensile Strength, Ksi	Notch Tensile Strength, Ksi	Elongation in 1 in., %	Area Reduction, %
850°F, 4 hr	206.3	226.4	288.9	16.5	41.3
	211.0	232.5	332.8	10.4	45.3
	244.1	258.8	351.6	8.3	44.8
	-	-	336.3	10.8	52.2
	241.6	259.6	329.1	8.0	48.0
Average	225.7	244.3	327.7	10.8	46.3
850°F, 8 hr	230.6	252.5	335.4	9.8	43.7
	253.8	268.8	318.2	7.6	45.3
	254.8	271.2	334.5	7.6	40.8
	220.2	239.5	346.4	9.0	47.5
	229.5	246.7	321.1	8.0	40.0
Average	237.8	255.7	331.1	8.4	43.5
850°F, 16 hr	-	256.6	357.9	7.5	36.0
	269.4	281.2	325.8	7.9	42.5
	261.2	275.2	351.4	8.6	46.8
	264.5	277.6	331.7	8.6	41.8
	249.5	266.6	349.0	7.2	42.9
Average	261.1	271.4	334.6	7.9	42.0
900°F, 1 hr	233.1	250.0	370.6	8.2	48.7
	215.0	235.1	334.6	9.6	48.3
	228.3	245.7	346.4	8.2	47.4
	221.8	241.9	227.3	8.6	46.8
	230.1	249.5	345.2	9.1	48.5
Average	225.7	244.4	324.8	8.7	47.9
900°F, 4 hr	247.9	265.7	346.7	8.0	46.2
	210.0	229.7	343.7	10.1	49.0
	227.9	250.0	360.6	9.7	48.5
	263.7	275.9	369.3	7.1	43.9
	246.7	264.8	300.0	8.8	43.8
Average	239.2	257.2	344.1	8.7	46.2
900°F, 8 hr	259.3	273.1	309.5	8.9	44.2
	238.6	257.9	310.3	8.8	45.2
	263.9	277.7	338.2	5.9	43.8
	265.6	278.2	368.5	7.2	43.6
Average	256.8	271.7	331.6	7.7	44.2
950°F, 1/2 hr	241.3	255.5	369.3	8.8	42.0
	240.7	253.8	342.6	7.1	38.6
	247.6	260.3	360.7	7.5	40.0
	253.5	265.3	346.1	9.1	43.6
	255.0	266.9	-	8.1	42.9
Average	247.6	260.3	354.7	8.1	41.4
950°F 1 hr	255.8	268.8	331.9	5.9	38.8
	241.4	247.0	335.4	7.0	41.4
	238.0	252.2	365.8	10.0	45.2
	257.7	268.4	359.1	7.5	40.4
	257.3	266.9		7.5	42.4
Average	250.0	260.7	348.0	7.6	41.6

TABLE 4

LONGITUDINAL TENSILE PROPERTIES OF STANDARD MATERIAL — TEST SERIES "B", BETHLEHEM 1/2-IN. PLATE, HEAT NO. 120D163 AS HOT-ROLLED AND AGED

Heat Treatment		0.2% Offset Yield Strength, ksi	Ultimate Tensile Strength, ksi	Elongation in 1 in., %	Area Reduction, %
850°F, 4 hr		240.0	257.0	12.3	45.0
		239.0	258.0	12.8	45.7
		241.0	257.0	11.3	48.8
	Average	240.0	257.8	12.1	46.5
850°F, 8 hr		249.0	262.0	10.7	45.0
		250.0	266.0	9.7	48.1
		250.0	265.0	9.2	40.0
	Average	249.6	264.5	9.8	44.3
850°F, 16 hr		253.0	268.0	10.0	34.3
		250.0	269.0	7.0	30.0
		258.0	266.0	10.2	43.5
	Average	253.8	267.6	9.0	35.9
900°F, 4 hr		243.5	260.0	9.7	41.5
		241.0	255.0	9.6	45.0
		238.0	252.8	10.4	46.5
	Average	240.8	255.9	10.0	44.3
900°F, 16 hr		-	275.0	7.0	21.1
		263.0	273.0	10.1	40.0
		259.0	273.0	6.6	28.6
	Average	261.0	273.7	7.9	29.9
950°F, 4 hr		239.3	251.5	9.8	42.7
		238.0	251.6	9.1	35.0
		238.5	250.5	10.0	46.7
	Average	239.5	251.2	9.6	41.4
950°F, 8 hr		251.5	263.4	9.3	47.7
		250.5	262.4	8.8	40.6
		251.5	264.3	9.3	44.5
	Average	251.1	263.3	9.1	44.3
950°F, 16 hr		227.1	240.3	10.8	45.2
		223.8	236.9	10.2	38.2
		225.4	238.2	10.7	47.2
	Average	225.4	238.5	10.6	43.5

TABLE 5

LONGITUDINAL TENSILE PROPERTIES OF STANDARD MATERIAL — TEST SERIES "C", BETHLEHEM 1/2-IN. PLATE, HEAT NO. 120D163 AS HOT-ROLLED AND AGED

Heat Treatment		0.2% Offset Yield Strength, ksi	Ultimate Tensile Strength, ksi	Elongation in 1 in., %	Area Reduction, %
850°F, 12 hr		259.3	271.0	10.9	47.5
		261.5	272.5	9.9	40.9
		259.3	273.0	9.9	43.5
	Average	260.0	272.2	9.9	43.9
850°F, 24 hr		266.3	276.9	10.5	39.8
		263.3	276.4	11.3	44.2
		264.5	275.5	10.2	44.5
	Average	264.7	276.3	10.7	42.8
900°F, 2 hr		246.6	261.5	9.7	47.3
		248.7	263.1	10.5	44.4
		247.4	262.5	11.9	40.9
	Average	247.5	262.3	10.7	44.2
900°F, 4 hr		248.0	261.8	9.3	33.8
		248.2	263.2	11.9	44.3
		247.0	261.5	10.4	39.3
	Average	247.6	262.3	10.5	39.1
900°F, 8 hr		246.8	260.4	11.9	48.2
		247.1	259.0	11.7	44.7
		242.5	253.3	12.7	44.5
	Average	245.5	257.6	11.9	45.8
900°F, 12 hr		248.0	260.9	11.5	47.2
		248.8	261.2	10.4	39.6
		249.2	263.0	11.9	37.0
	Average	248.7	261.7	11.3	41.3

TABLE 5 (cont.)

Heat Treatment	0.2% Offset Yield Strength, ksi	Ultimate Tensile Strength, ksi	Elongation in 1 in., %	Area Reduction, %
900°F, 24 hr	247.1	261.2	12.5	48.1
	249.5	263.0	10.7	37.6
	252.0	266.0	11.0	48.2
Average	249.5	263.4	11.4	44.6
950°F, 2 hr	247.3	259.3	11.8	50.0
	249.8	264.2	9.7	47.3
	243.2	253.4	-	-
Average	246.8	258.9	10.7	48.5
950°F, 4 hr	227.0	242.0	11.3	48.3
	224.2	238.0	13.6	44.5
	223.0	239.7	12.9	40.8
Average	224.7	239.3	12.6	44.5
950°F, 8 hr	231.0	245.5	14.9	51.8
	227.5	242.6	15.6	50.7
	231.0	245.0	14.1	48.2
Average	229.8	244.4	14.9	50.2

TABLE 6

TRANSVERSE TENSILE PROPERTIES OF STANDARD MATERIAL
BETHLEHEM STEEL HEAT NO. 120D163
AS HOT-ROLLED AND AGED

Heat Treatment		0.2% Offset Yield Strength, ksi	Ultimate Tensile Strength, ksi	Notch Tensile Strength, ksi	Elongation in 1 in., %	Area Reduction, %
850°F, 4 hr		236.6	256.4	322.0	7.5	25.0
		238.7	254.9	330.0	9.4	42.6
		242.2	259.7	313.0	8.2	32.9
	Average	239.2	257.0	321.7	8.4	33.5
850°F, 8 hr		264.1	276.7	307.0	7.0	36.4
		264.8	276.1	323.0	7.2	34.9
		262.3	276.6	318.5	7.2	30.6
	Average	263.7	276.5	316.2	7.2	34.0
900°F, 4 hr		236.9	251.9	309.5	9.4	40.2
		238.2	251.5	269.0	8.8	34.4
		259.8	272.0	355.0	8.0	36.7
	Average	245.0	258.5	311.2	8.7	37.1
950°F, 2 hr		256.4	269.7	296.0	9.5	37.5
		258.1	271.7	319.0	7.1	38.4
		253.0	266.5	285.0	6.8	31.5
	Average	255.8	269.3	300.0	7.8	35.8
950°F, 4 hr		253.4	267.2	318.5	9.3	38.1
		254.9	266.3	279.0	7.7	36.1
		252.5	267.2	307.0	4.1	13.8
	Average	253.6	266.9	301.5	7.0	29.3

TABEL 7

AGING RESPONSE OF AIR-MELTED 250-KSI MATERIAL, UNITED STATES STEEL 1/2-IN. PLATE, HEAT NO. X-43371 AS HOT-ROLLED AND AGED

Heat Treatment	Specimen Orientation	0.2% Offset Yield Strength, Ksi	Ultimate Tensile Strength, Ksi	Notch Tensile Strength, Ksi	Elongation in 1 in., %	Area Reduction, %
850°F, 4 hr	Longitudinal	226.8	240.1		9.5	43.0
	Longitudinal	229.1	245.0		9.5	42.5
	Longitudinal	234.7	247.0		10.5	45.7
	Average	230.2	244.0		9.8	43.7
850°F, 8 hr	Longitudinal	260.3	271.5		10.0	38.6
	Longitudinal	266.9	274.5		9.0	38.6
	Longitudinal	264.0	273.3		8.4	38.2
	Average	263.7	239.8		9.1	38.5
900°F, 4 hr	Longitudinal	243.5	259.5	305.0	11.0	40.1
	Longitudinal	248.0	259.5	269.0	11.5	39.4
	Longitudinal	244.5	257.0	262.0	10.4	40.8
	Average	245.3	258.7	278.7	11.0	40.1
	Transverse	236.5	252.5	313.0	9.4	38.1
	Transverse	251.0	263.0	311.5	8.4	43.7
	Transverse	234.0	249.5	281.0	12.0	43.8
	Average	240.5	255.0	301.8	9.9	41.9
950°F, 2 hr	Longitudinal	264.0	272.5	298.0	7.6	37.0
	Longitudinal	264.0	275.0	293.5	9.0	38.8
	Longitudinal	272.0	280.5	246.5	7.7	33.3
	Average	266.7	276.0	279.3	8.1	36.4
	Transverse	244.0	257.5	290.0	10.4	38.6
	Transverse	245.5	264.0	277.5	8.6	42.2
	Transverse	246.5	260.0	304.0	10.3	36.9
	Average	245.3	260.5	290.5	9.8	39.2
950°F, 4 hr	Longitudinal	263.0	275.0	238.0	6.8	33.8
	Longitudinal	263.0	273.0	291.0	5.9	32.2
	Longitudinal	261.0	272.5	303.5	9.0	40.8
	Average	261.4	273.5	277.5	7.2	35.6

TABLE 8

AGING RESPONSE OF VACUUM ARC-REMELTED 250-KSI MATERIAL, REPUBLIC STEEL 1/2-IN. PLATE, HEAT NO. 3888471 AS HOT-ROLLED AND AGED

Heat Treatment	Specimen Orientation	0.2% Offset Yield Strength, Ksi	Ultimate Tensile Strength, Ksi	Notch Tensile Strength, Ksi	Elongation in 1 in., %	Area Reduction, %
850°F, 4 hr	Longitudinal	189.5	213.5	271.5	15.5	46.5
	Longitudinal	183.5	208.5	275.0	16.0	49.2
	Longitudinal	214.5	229.5	271.5	10.8	33.9
	Average	195.8	217.2	272.7	14.1	43.2
850°F, 8 hr	Longitudinal	204.0	219.0	263.5	14.3	43.8
	Longitudinal	207.0	222.5	269.5	13.1	41.5
	Longitudinal	208.0	229.5	275.0	12.5	44.0
	Average	206.3	223.7	269.3	13.3	43.1
900°F, 4 hr	Longitudinal	215.5	232.5	247.5	11.5	38.0
	Longitudinal	210.2	229.6	279.0	12.1	42.8
	Longitudinal	176.1	205.3	278.0	14.9	49.5
	Average	200.6	222.5	268.2	12.8	43.4
	Transverse	209.4	229.5	276.0	11.3	35.4
	Transverse	202.8	221.9	241.5	11.9	38.0
	Transverse	179.5	206.5	290.0	15.8	47.5
	Average	197.2	219.3	269.2	13.0	40.3
950°F, 2 hr	Longitudinal	181.0	207.9	265.0	15.1	48.6
	Longitudinal	191.7	213.6	223.0	16.4	49.5
	Longitudinal	204.5	225.0	282.0	13.0	47.3
	Average	192.4	215.5	256.7	14.8	48.5
	Transverse	212.8	230.9	264.5	11.2	34.9
	Transverse	181.0	208.4	268.5	12.5	38.6
	Transverse	173.9	207.6	270.0	11.0	38.2
	Average	189.2	215.6	267.7	11.6	37.2
950°F, 4 hr	Longitudinal	195.7	219.2	287.5	13.4	42.3
	Longitudinal	203.9	226.2	254.5	11.8	41.3
	Longitudinal	206.3	227.7	288.0	11.2	39.6
	Average	202.0	224.4	276.7	12.1	41.1

TABLE 9

TYPICAL PROCESS PARAMETERS USED TO TIG-WELD 1/2-IN. -THICK 18%-NICKEL MARAGING STEEL

Weld Pass No.	Current amp	Voltage	Travel Speed, in. /min	Wire Speed, in. /min	Argon Gas Flow (CFM) Torch	Argon Gas Flow (CFM) Back Up
1	150	10	6	18	25	10
2	150	8.5	6	18	25	10
3	160	10	6	24	25	10
4	160	10	6	24	25	10
5	180	10	6	24	25	10
6	180	10	6	24	25	10
7	180	10	7	24	25	10
8	180	10	7	24	25	10
9	180	10	7	24	25	10
10	180	10	7	24	25	10

TABLE 10

CHEMICAL COMPOSITION OF WELD WIRES AND 18%-NICKEL MARAGING STEEL EMPLOYED IN WELDING EVALUATIONS

(Mill-Certified Analyses)

Vendor and Heat No.	C	Mn	P	S	Si	Ni	Al	Ti	Mo	Co
Special Metals Wire Heat No. 34312	0.020	0.01	0.005	0.009	0.010	17.90	0.19	0.50	4.45	8.0
A.L. Wire Heat No. 7C-090	0.030	0.002	0.004	0.006	0.012	18.02	0.015	1.54	4.17	8.02
A.L. Wire Heat No. 7C-091	0.022	0.002	0.004	0.006	0.012	18.01	0.016	0.71	4.22	11.90
A.L. Wire Heat No. 7C-092	0.027	0.003	0.003	0.008	0.047	18.05	0.016	0.71	5.30	7.03
A.L. Wire Heat No. 7C-093	0.030	0.003	0.004	0.006	0.012	18.10	0.016	0.65	4.17	8.07
A.L. Wire Heat No. 7C-094	0.024	0.002	0.004	0.007	0.009	17.68	0.017	0.91	4.24	9.93
Bethlehem Plate Heat No. 120D163	0.017	0.06	0.005	0.004	0.18	17.84	0.12	0.55	4.80	8.25

TABLE 11

MECHANICAL PROPERTIES OF TIG-WELDED 18% Ni MARAGING STEEL
(All Test Specimens Oriented Transverse to Weld)

Weld Wire Heat No.	%Ti	%Co	0.2% Offset Yield Strength, ksi	Ultimate Tensile Strength, ksi	Elongation, %	RA,[3] %	Fracture[9] Location[2]	Notch Tensile[3] Strength, ksi
7C-090	1.64	8.0	246.5	261.6	6.6	35.4	PM	257.7 (4)
			249.5	254.6	1.0	0.0 (3)	Weld	229.2 (4)
			252.6	265.9	7.3	38.6	HAZ	264.1 (4)
		Average	249.5	260.7	6.9	37.0		250.3
7C-091	0.71	12.0	251.5	264.9	5.0	25.5	PM	176.6
			256.8	268.6	7.1	31.2	PM	169.5
			247.0	259.4	2.1	2.5 (5)	PM	192.6
		Average	251.8	263.8	6.0	28.3		179.6
7C-092	0.71	7.0	243.4	259.6	1.5	7.1(5)	Weld	127.9
			248.0	259.6	1.5	4.8(5)	Weld	216.1
			244.9	259.6	6.3	28.7	HAZ	173.0
		Average	254.4	259.6	6.3	28.7		177.3
7C-093	0.65	8.0	249.5	258.1	4.8	27.5	Weld	259.3
			250.0	261.6	5.0	19.6	Weld	252.1
			250.0	259.8	7.0	25.5	Weld	276.9
		Average	249.8	259.8	5.6	24.2		261.1
7C-094	0.91	9.0	249.5	262.2	7.1	41.1	HAZ	246.6
			238.1	241.7	0.5	0.0(4)	Weld	208.9
			249.5	260.3	5.7	19.7	HAZ	193.0
		Average	245.7	254.7	6.4	20.4		216.7
34312	0.50	8.0	251.5	260.3	6.6	29.6	Weld	291.4
			248.0	258.0	4.9	20.6	Weld	151.4
			250.0	257.6	5.8	28.1	Weld	191.7
		Average	249.8	258.6	5.8	26.1		211.5

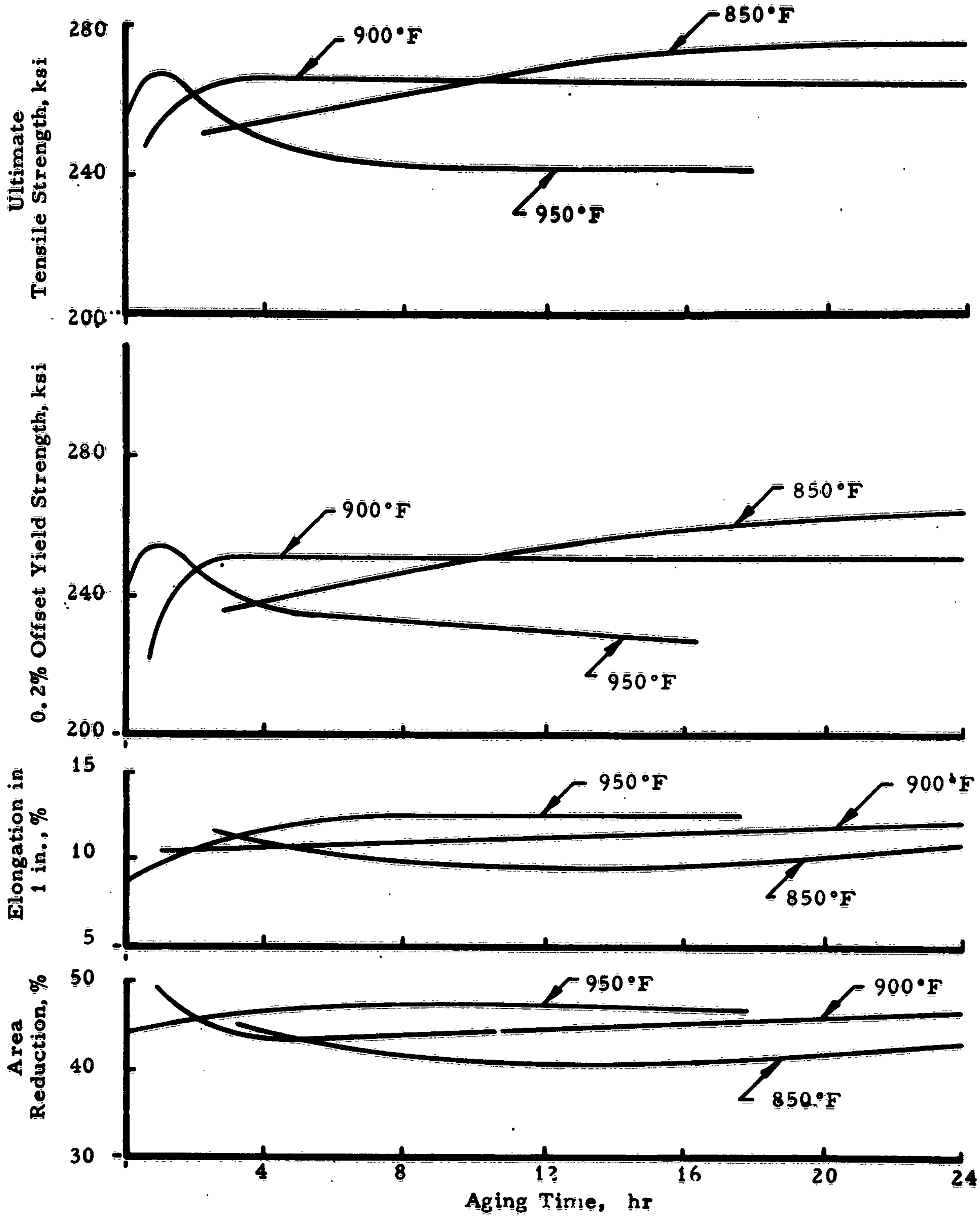
(1) Chemical Analysis in Table 10
(2) PM=parent metal HAZ=heat-affected zone
(3) Excessive porosity
(4) Excessive inclusions
(5) Machining defect.

TABLE 12

RADIOGRAPHIC INSPECTION RESULTS FOR 18%-NICKEL MARAGING STEEL WELD TEST PLATES (TIG WELDS; PARAMETERS, TABLE 11)

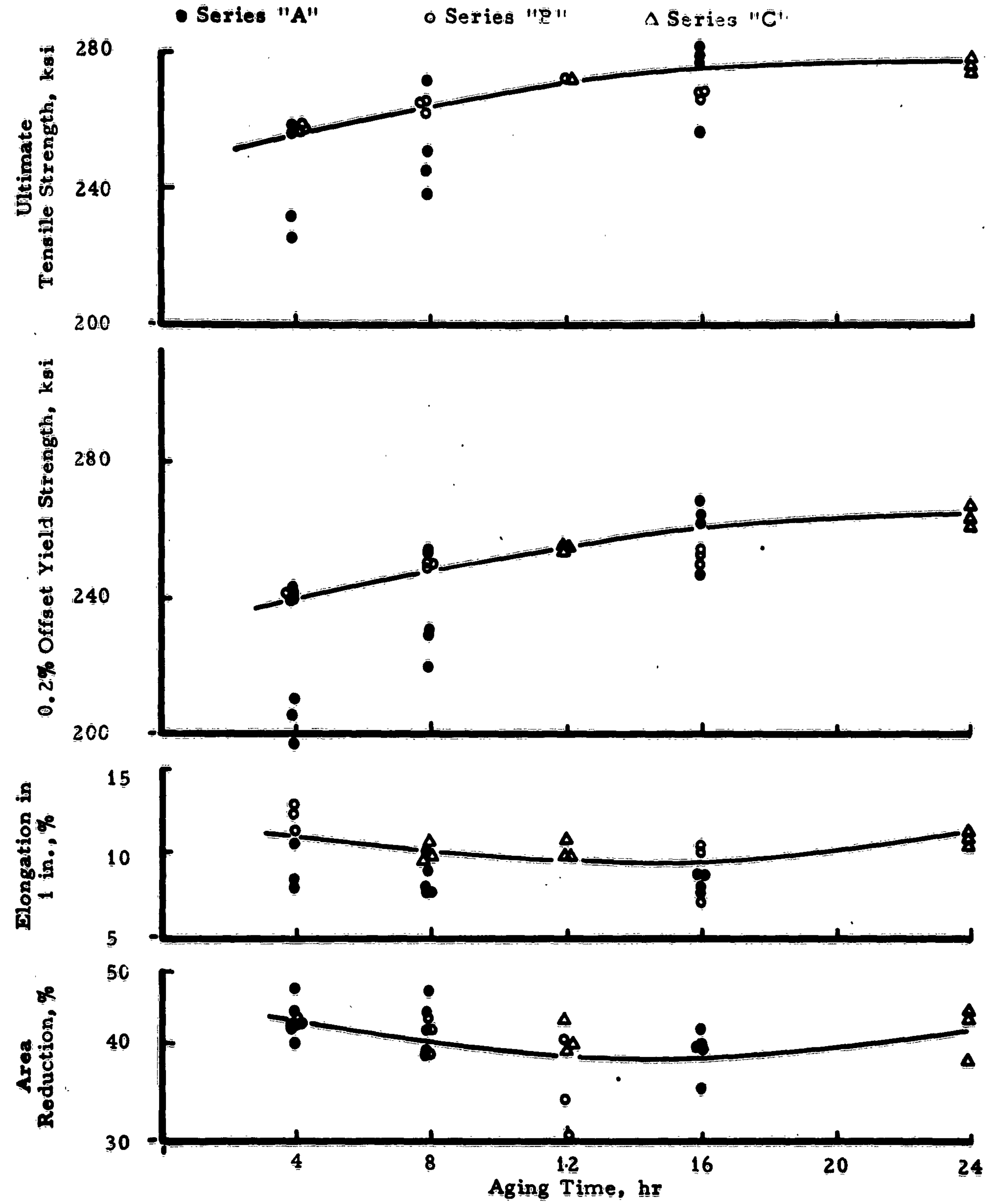
		X-Ray Results*			
Weld Wire Heat No.	Weld Identity	General Quality	Scattered Porosity	Linear Porosity	Inclusions
7C-090	MO-2	R	R	R	A
	MG-2	R	R	R	R
	MJ-2	A	A (fine)	A	A
	MQ-1	R	R	R	A
7C-091	ME-1	R	R	A	R
	MH-1	R	A	R	A
	MK-1	A	A	A	A (fine)
	MQ-2	A	A	A	A
7C-092	ME-2	A	A (fine)	A	A (fine)
	MH-2	A	A	A (fine)	A
	MK-2	A	A	A	A (fine)
	MQ-3	A	A (fine)	A	A
7C-093	MF-1	A	A	A	A
	MI- 1	A	A	A	A (3 spots)
	ML-1	A	A	A	A
	MR-1	A	A	A	A
7C-094	MF-2	A	A (fine)	A (fine)	A
	MI- 2	R	R	R	A
	ML-2	R	R	R	A
	MP-1	A	A	A (borderline)	A
34312	MF-3	R	R	A	A
	MG-1	A	A (fine)	A	A
	MJ-1	A	A	A	A
	MR-2	A	A	A	A

*All test plates were also dye-penetrant-inspected; no cracking was detected.
A = Accept
R = Reject



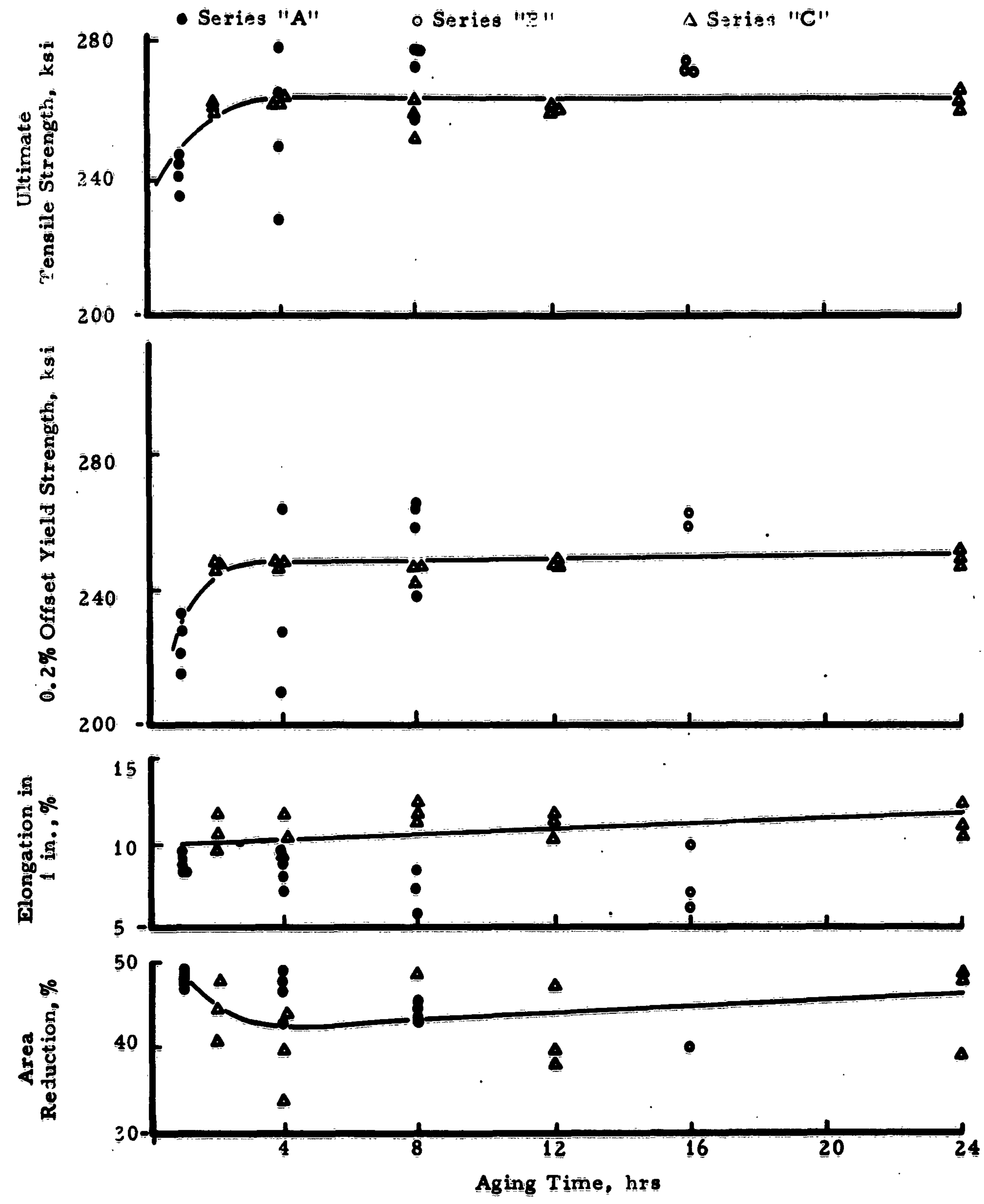
Effect of Aging Temperature and Time on Mechanical Properties of 18%-Ni Maraging Steel

Figure 1



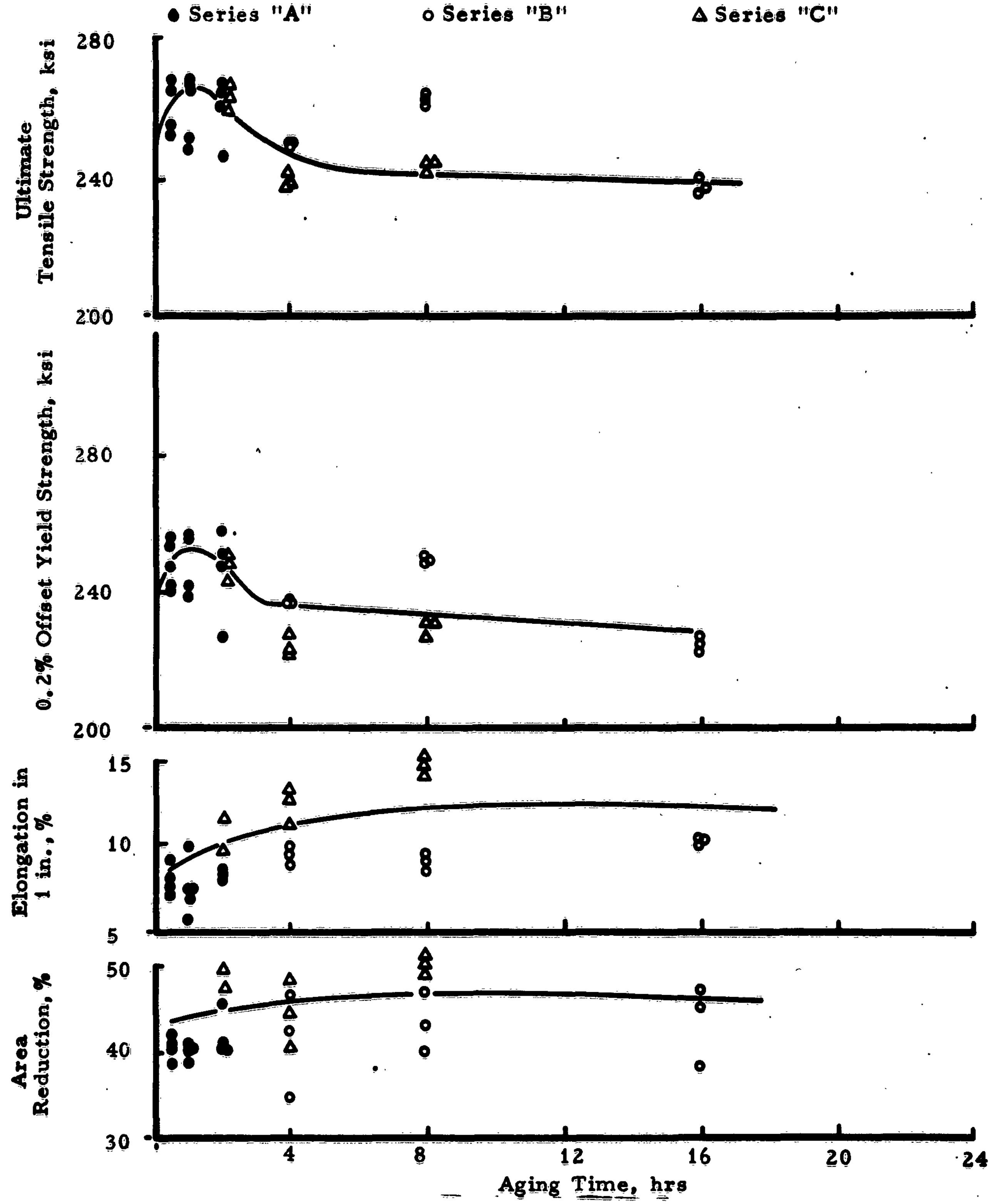
Effect of Aging Time at 850°F on Mechanical Properties of 18%-Ni Maraging Steel

Figure 2



Effect of Aging Time at 900°F on Mechanical Properties of 18%-Ni Maraging Steel

Figure 3



Effect of Aging Time at 950°F on Mechanical Properties of 18%-Ni Maraging Steel

Figure 4

APPENDIX A

TENTATIVE MATERIAL SPECIFICATION

APPENDIX A

DEVELOPMENT MATERIAL SPECIFICATION

STEEL PLATES, SHEETS, AND STRIPS; MARAGING; HIGH-STRENGTH, 18% NICKEL

1. SCOPE

1.1 Scope. This specification covers Maraging steel alloys in plate, sheet, and strip form.

1.2 Classification. The steel shall be classified according to the approximate yield strength of the steel in thousands of pounds per square inch (ksi).

Material Class	Yield Strength, ksi
200	200
235	235
250	250
300	300

2. APPLICABLE DOCUMENTS

2.1 Governmental documents. The following document of the issue as listed in the Department of Defense Index of Specifications and Standards in effect on the date of invitation for bids shall form a part of this specification to the extent specified herein.

STANDARD

Federal

Fed. Test Method Std. No. 151	Metals, Test Methods
Fed. Std. No. 183	Continuous Identification Markings of Iron and Steel Products

(Copies of specifications, standards, drawings, and publications required by contractors in connection with specific procurement functions should be obtained from the Superintendent of Documents, Government Printing Office, Washington 25, D. C.)

2.2 Other publications. The following documents form a part of this specification to the extent specified herein. Unless otherwise specified, the issue in effect on the date of invitation for bids shall apply.

SPECIFICATION

Society of Automotive Engineers

AMS-2252	Tolerances — Alloy Steel Sheet Strip and Plate

(Copies may be obtained from the Society of Automotive Engineers, Inc., 485 Lexington Avenue, New York 17, New York.)

STANDARD

American Society for Testing Materials

ASTM E 45	Recommended Practice for Determining the Inclusion Content of Steel

(Copies may be obtained from the American Society for Testing Materials, 1916 Race Street, Philadelphia 3, Pennsylvania.)

3. REQUIREMENTS

3.1 Chemical composition. The Steel shall contain the indicated percentages of the following elements:

	Material Class							
	200		235		250		300	
Element	Min	Max	Min	Max	Min	Max	Min	Max
Carbon	---	0.03	---	.03	---	0.03	---	0.03
Manganese	---	0.10	---	.10	---	0.10	---	0.10
Silicon	---	0.10	---	.10	---	0.10	---	0.10
Phosphorus	---	0.025	---	.025	---	0.025	---	0.025
Sulfur	---	0.01	---	.10	---	0.01	---	0.01
Nickel	17.5	19.0	17.5	18.5	18.0	19.0	18.0	19.0
Titanium	0.10	0.25	.25	.40	0.40	0.65	0.65	0.85
Aluminum	0.05	0.15	.05	.15	0.05	0.15	0.1	0.4
Cobalt	6.5	7.5	6.5	7.5	7.0	8.0	8.0	10.0
Molybdenum	3.5	4.5	4.5	5.5	4.5	5.5	4.5	5.5

3.2 Melting practice. The melting practice used in the manufacture of the steel shall be in accordance with the following, as specified in the purchase order:

		Material Class			
	Melting Practice	200	235	250	300
(a)	Air melted	X			
(b)	Vacuum degassed	X	X	X	
(c)	Vacuum-induction melted	X	X	X	
(d)	Vacuum-arc remelted		X	X	X

3.2.1 Additives. The supplier shall certify that the indicated amounts of the following materials were added to the steel during melting:

	Material		Amount, %
(a)	Boron		0.003
(b)	Zirconium		0.02
(c)	Calcium	.06 in increments of	0.02

3.3 Solution treatment. The material shall be furnished in the solution-treated condition. Solution treatment shall be such that the material is maintained at a temperature of 1500 ± 25°F for 1 hr/in. of cross section.

3.4 Mechanical properties. The material shall be capable of meeting the required yield strength (0.2% offset) indicated by the material class being procured. To ensure that this strength level is attained, tensile specimens will be solution-annealed as indicated in paragraph 3.3, Solution Treatment, and aged at temperatures of 850-950°F for times of 2-8 hr. Sufficient aging time-temperature cycles within these limits shall be evaluated to accurately establish the aging response of each heat of material being procured and to ensure that the required minimum yield strength can be reliably attained.

3.5 Grain size. The grain size shall be determined and the results reported.

3.6 Inclusion rating. Inclusion-rating tests shall be made and the results reported. The inclusion rating shall be based on the worst area of inclusions found in the test specimens evaluated and shall not exceed the following:

Series

Thin	Heavy
A 1 1/2	A 1
B 1 1/2	B 1
C 1 1/2	C 1
D 2	D 1 1/2

3.7 Tolerances. Tolerances shall be in accordance with Specification AMS-2252.

3.8 Reports. With each shipment, the supplier shall furnish three copies of a report of the results of the tests for mechanical properties, chemical composition, grain size, and inclusion rating of each heat in the shipment. This report shall include the purchase-order number, specification number, size, class, and quantity from each heat.

3.9 Workmanship. The steel shall be uniform in quality and shall be free from pits, die marks, rust, excessive scale, scrapes, splits, laps, cracks, seams, and any other defect that could interfere with its use.

4. QUALITY ASSURANCE PROVISIONS

4.1 Supplier responsibility.

4.1.1 Inspection and records. The supplier is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified, the supplier may utilize his own or any other inspection facilities and services acceptable to the procuring activity. Inspection facilities and services acceptable to the procuring activity. Inspection records of the

examination and tests shall be kept complete and available to the procuring activity. The procuring activity reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure that supplies and services conform to prescribed requirements.

4.1.2 Processing changes. The supplier shall make no changes in processing techniques or other factors affecting the quality of the product without prior approval of the procuring activity.

4.2 Sampling. Preparation of samples shall be in accordance with Standard Fed. Test Method Std. No. 151. Selection of samples shall be as follows:

a. Chemical Composition — each sheet or plate

b. Austenitic Grain Size — one sample from each plate or sheet

c. Inclusion Content — each sheet or plate

d. Mechanical Properties — each sheet or plate

e. Thickness — each sheet or plate

f. Visual Examination — each sheet or plate

g. Magnetic Particle — each sheet or plate

h. Ultrasonic — each sheet or plate

4.3 Lot size. Each heat shall constitute a lot.

4.4 Testing. Testing shall be in accordance with the following methods:

		Method
(a)	Chemical composition	Fed. Test Method Std. No. 151
(b)	Grain size	Fed. Test Method Std. No. 151, method 311
(c)	Inclusion rating	ASTM E 45
(d)	Tolerance	AMS-2252
(e)	Tension test	Method 211 (std 151)
(f)	Hardness	Method 243 (std 151)

4.5 Examination. The steel and its packaging, packing, and marking shall be examined for conformance with 3.8 and section 5.

5. PREPARATION FOR DELIVERY

5.1 Packaging and packing. The steel shall be packaged and packed in a manner that will prevent scratching or other damage during shipping and other handling.

5.2 Marking. Each sheet, plate, or strip shall be marked with ink in accordance with Standard Fed. Std. No. 183 and shall include, but not be limited to, the following:

(a) Number of this specification.
(b) Material classification.
(c) Manufacturer's name
(d) Heat number.
(e) Nominal thickness.

6. NOTES

6.1 Intended use. The 18% nickel steel sheets, plates, and strips are intended for use in rocket motors.

6.2 Ordering data. Procurement documents shall include, but not be limited to, the following information:

- (a) Classification of steel.
- (b) Number of this specification.
- (c) Manufacturer's name.
- (d) Form (sheet, plate, or strip).
- (e) Nominal thickness.
- (f) Melting practice.